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As ocean surface waves propagate over the continental shelf and break in shallow nearshore areas, their energy is dissipated in the surf zone. The gradients in the wavelets and momentum give rise to the generation of wave-induced nearshore circulation Wave forcing of circulation in the surf zone is a major cause of sediment transport and beach morphology evolution; its understanding and prediction are essential from military application such as amphibious landings and mine warfare. Semiempirical expressions for the nearshore circulation exist over planar bathymetry. However, over more complex bathymetric configurations, such as sandbars, rip channels, and canyons, numerical models are required form comprehensive descriptions of the wave-driven flow. Most of these extant numerical models either use irregular wave forcing but simplify the hydrodynamics (as is the cases for nearshore circulation models in the operational Navy), or allow more involved hydrodynamic formulations but reduce the forcing to that of monochromatic wave theory. Wither modeling option can potentially lead to nearshore hydrodynamic predictions that do not exhibit the variability seen in nature.

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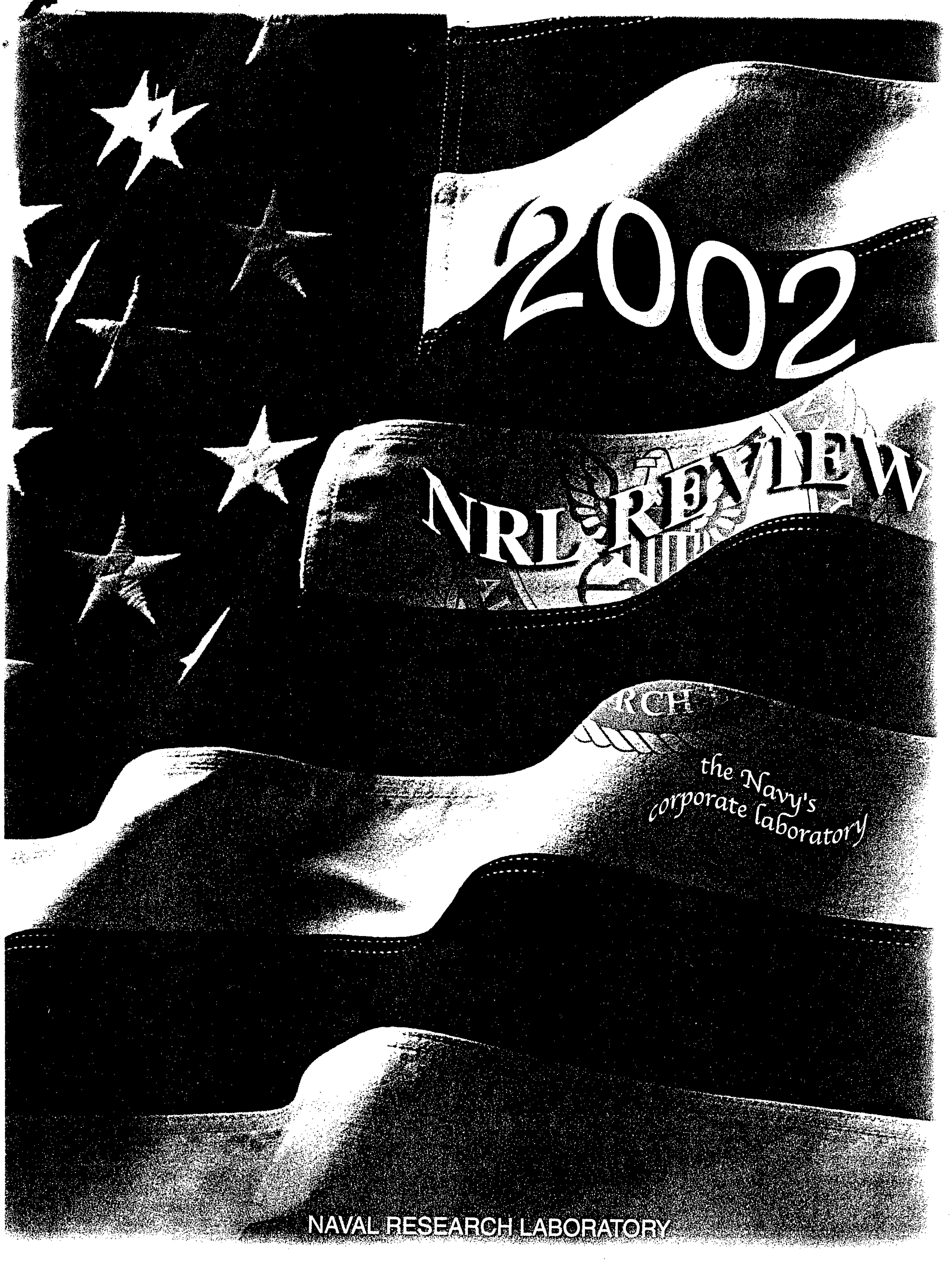
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Nearshore Circulation in Complex Regions

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Oceanography Division

Introduction: As ocean surface waves propagate over the continental shelf and break in shallow nearshore areas, their energy is dissipated in the surf zone. The gradients in the waveheights and momentum give rise to the generation of wave-induced nearshore circulation. Wave forcing of circulation in the surf zone is a major cause of sediment transport and beach morphology evolution; its understanding and prediction are essential for military applications such as amphibious landings and mine warfare. Semi-empirical expressions for the nearshore circulation exist over planar bathymetry. However, over more complex bathymetric configurations, such as sandbars, rip channels, and canyons, numerical models are required for comprehensive descriptions of the wave-driven flow. Most of these extant numerical models either use irregular wave forcing but simplify the hydrodynamics (as is the case for nearshore circulation models in the operational Navy), or allow more involved hydrodynamic formulations but reduce the forcing to that of monochromatic wave theory. Either modeling option can potentially lead to nearshore hydrodynamic predictions that do not exhibit the variability seen in nature.

Numerical Modeling of Nearshore Circulation: Recently, the Naval Research Laboratory (NRL) developed significant modifications to a sophisticated quasi-three-dimensional (quasi-3D) numerical hydrodynamic model. This model, SHORECIRC, was developed by Dr. Ib Svendsen and students at the Center for Applied Coastal Research of the University of Delaware. It is "quasi-3D" in that it actively models the depth-averaged horizontal velocities, but uses sophisticated analytic expressions to calculate the vertical profile of these horizontal velocities. The model is therefore able to simulate the evolution of horizontal velocities of the nearshore circulation field (including the depth-varying offshore flow, or "undertow") in all three dimensions (and time) without large computational effort. However, its physical mechanisms were geared toward monochromatic (single frequency) wave forcing, and thus are not applicable to field cases where waves of many frequencies and directions are present. NRL performed the reformulation of these physical mechanisms by adopting a probability distribution of waveheights inside the surf zone, and then integrating existing monochromatic formulations over this distribution. The resulting model represents the first implementation of random wave forcing in a general quasi-3D hydrodynamic model, thus allowing direct application to field situations.

Application to Nearshore Canyon: A major nearshore measurement campaign for the 2003-2004 time frame will be conducted near the Scripps Institution of Oceanography in La Jolla, California. This field experiment will be a collaborative effort among several universities and research institutions, including NRL. The site of the experiment is located at the head of Scripps Canyon, a major undersea canyon that exerts a strong polarizing effect on the nearshore wave and circulation climate. Figure 3 shows an aerial photograph of Black's Beach, located at the head of Scripps Canyon, taken by Dr. Steve Elgar of Woods Hole Oceanographic Institution. The

FIGURE 3
Aerial photograph of Black's Beach, north of Scripps Canyon in California. The undersea canyon enacts a strong variability on the nearshore wave and circulation environment. Arrows trace the presumed longshore and rip current patterns. Photo courtesy of Dr. Steve Elgar, Woods Hole Oceanographic Institution.

high variability in the wavefield and complex rip current environment is evident.

NRL developed a nested modeling system to investigate the possible nearshore flow patterns at this site, using the reformulated SHORECIRC model at the finest nest. The coastal-scale wave model SWAN (developed at Delft Technical University) propagated offshore wave energy into the nearshore canyon site. Figure 4 shows the waveheight prediction from SWAN over the entire domain, which was resolved at ~30 m in both directions. Information from SWAN was then input to a high-resolution nearshore irregular wave model (REF/DIF-S, developed at the University of Delaware) for simulating wave propagation over the small area in the white box near Black's Beach (at ~4-m resolution in both directions). The high-resolution wave model results were then used for forcing in the reformulated SHORECIRC model. Figure 5 shows the predicted average nearshore circulation pattern. The pair of northward-directed rip currents qualitatively represents what is seen in Fig. 3. No attempt was made to simulate the exact condition depicted in Fig. 3, so the rip current pair is probably more a direct result of the complex bathymetry than the wave climate offshore of the domain, and thus is likely to be a persistent feature.

Summary: NRL has developed significant modifications to the quasi-3D hydrodynamic model SHORECIRC. The most essential of these modifications (irregular wave forcing) enables the modeling of nearshore circulation without gross simplification of actual conditions. NRL developed a nested modeling system for the Scripps Canyon area, the site of an upcoming measurement campaign, and used this system to investigate potential flow conditions in the area. The presence of a rip current pair in the results qualitatively agrees with observations in the area. The NRL-enhanced SHORECIRC model shows promise as a forecasting tool, and further model validation is aimed toward this evaluation.

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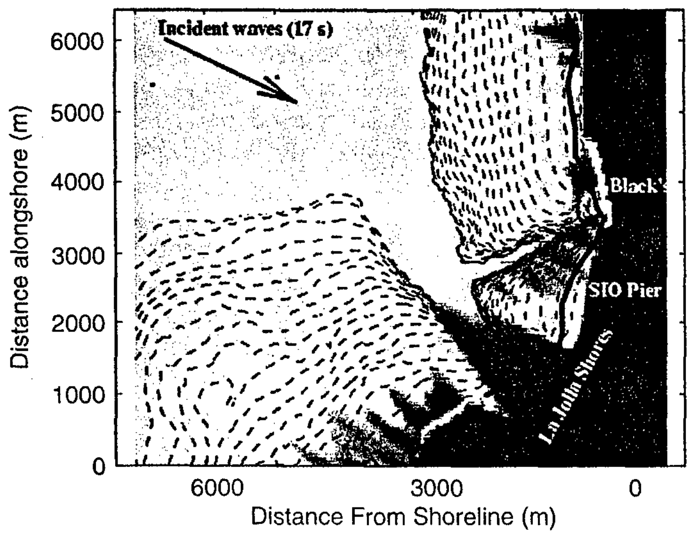

FIGURE 4
NRL model nest at Scripps Canyon: waveheights from the SWAN wave model over the shelf area near Scripps Canyon and Black's Beach. North is upward. Wave spectra with offshore height of 2 m and peak period of 17 s approach from the northwest. Waveheights over the domain range from 4 m (darkest red) to 0.25 m (deepest blue). Results are input into high-resolution wave and hydrodynamic models near Black's Beach (white rectangle).

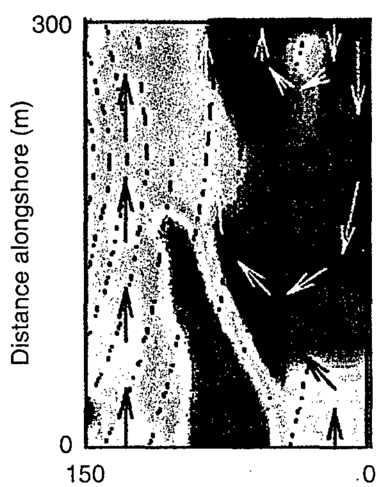

FIGURE 5
NRL model nest at Scripps Canyon: predicted nearshore circulation pattern at Black's Beach from NRL-modified SHORECIRC model. Colors denote magnitude of longshore (north-south) velocities; range is from 1 m/s northward (dark red) to 1 m/s southward (deep blue). Arrows denote nearshore circulation pattern. Rip current pair (white arrows) are persistent features in simulations in this area, thus suggesting strong bathymetric influence on current patterns and milder sensitivity to nature of offshore conditions.